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Impoverished environment, cognition, aging and dementia

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Abstract

Animals living in an impoverished environment, i.e., without the possibility of physical and social activity, perform worse on cognitive tests compared to animals in an enriched environment. The same cognitive difference is also observed in humans. However, it is not clear whether this difference is caused by a decrease in cognition due to an impoverished environment or an increase due to an enriched environment. This review discusses the impact of an impoverished environment on cognition in animal experimental studies and human experimental studies with community-dwelling and institutionalized older people. Results show that the cognitive functioning of old rats is more affected by an impoverished environment than young rats. Similarly, sedentary and lonely people (impoverished environment) have worse cognitive functioning and show a faster cognitive decline than physically and socially active people. Institutionalization further aggravates cognitive decline, probably due to the impoverished environment of nursing homes. In institutions, residents spend an unnecessary and excessive amount of time in bed; out of bed they show mainly sedentary or completely passive behavior. In conclusion, older people, especially those that have been institutionalized, have poor levels of physical and social activity, which in turn has a negative impact on cognitive functioning.

Keywords: aging; dementia; elderly; impoverished environment; isolation; loneliness; physical activity.

Introduction

Epidemiological studies show a positive relationship between physical activity and cognition (Hamer and Chida, 2009). More specifically, a high level of physical activity during life is related to lower rates of dementia and might even protect against dementia (Middleton et al., 2010; Radak et al., 2010). Correspondingly, a low level of physical activity during life is related to higher rates of dementia and might increase the risk of developing dementia (Hamer and Chida, 2009; Middleton et al., 2010; Radak et al., 2010). A mechanism underlying these findings is that a low level of physical activity is related to a smaller volume of the hippocampus (Erickson et al.,

2009), an area in the medial temporal lobe that is involved in long-term memory and spatial navigation (Lui et al., 2011). It is important to note that these studies only show a ‘relationship’ between physical activity and cognition, not a ‘causal’ relationship.

A causal relationship, i.e., an effect of physical activity on cognition, is shown by intervention studies with children (Tomprowski et al., 2008), adolescents (Budde et al., 2008), older cognitive healthy people (Angevaren et al., 2008), persons with mild cognitive impairment (Lam et al., 2010) and older persons with Alzheimer’s disease (Yaguez et al., 2011). Results of the studies with older people show that particularly executive functions such as inhibition, scheduling, planning and working memory respond positively to an increase in physical activity (Colcombe and Kramer, 2003; Kramer et al., 2005, 2006; Scherder et al., 2005). One of the brain areas that plays a crucial role in executive functions is the prefrontal cortex (PFC) (Elderkin-Thompson et al., 2008). Indeed, the PFC reacts positively to physical activity (Rosano et al., 2010). Physical activity is part of an enriched environment, together with socialization (Studenski et al., 2006). It is known that an enriched environment induces a variety of neurophysiological changes, e.g., neurogenesis (Aberg et al., 2006). Living in an enriched environment could also improve cognition, i.e., learning and memory (Winocur, 1998; Williams and Kemper, 2010).

Considering the positive effect of an enriched environment on cognition, the question arises whether an impoverished environment will worsen cognitive functions. This question is of clinical relevance, as passivity is common among residents in nursing homes (Egerton and Brauer, 2009; Scherder et al., 2010), but often not acknowledged as a noteworthy behavior (Kolanowski et al., 2010).

Therefore, the goal of the present review is to address studies that examined the effect of an impoverished environment on cognition in older animals and in older persons with and without dementia. An impoverished environment includes physical inactivity and loneliness, or even worse, passivity and isolation. Animal experimental studies will be discussed first, followed by clinical studies including older people living in society and in institutions both with and without dementia.

Animal experimental studies

There is ample evidence that animals living in an impoverished environment perform worse on cognitive tests compared to those living in an enriched environment (Kubanis et al., 1982; Mohammed et al., 1993; Winterfeld et al., 1998; Schrijver et al., 2004; Teather and Wurtman, 2005, 2006; Bartesaghi et al., 2006; Gregory and Szumlinski, 2008; Diniz

et al., 2010). However, these results do not indicate whether these differences are caused by a decrease in cognition due to the impoverished environment or by an increase due to the enriched environment. Therefore, within the scope of the present review, we will address studies that compared an impoverished environment with a 'standard' environment.

A first interesting finding is that old rats are more influenced by environmental conditions compared to young or mature rats (Winocur, 1998; Bell et al., 2009). Especially in impoverished environments, i.e., environments without possibilities to be physically active (e.g., due to immobilization) and without social interaction, aged rats are more affected than young rats (Winocur, 1998). In this one available study, old rats living in an impoverished environment for 92 days showed a decline in learning and memory compared to rats in a standard environment (Winocur, 1998). A mechanism underlying this finding might be that an impoverished environment contributes to a reduced density of metabotropic glutamate receptors in the PFC which results in impaired working memory (Melendez et al., 2004; Gregory and Szumlinski, 2008). Interestingly, the cognitive impairments observed after three months of impoverished environment in old rats were reversible (Winocur, 1998). When old rats were transferred from an impoverished to an enriched environment for an additional three months, their cognitive performance improved with 32% (Winocur, 1998). An opposite transfer, from a standard to an impoverished environment, caused a cognitive decline of 74% (Winocur, 1998). Rats with the worst cognitive performances were housed in an impoverished environment for six consecutive months (Winocur, 1998).

Isolation

As mentioned above, an environment restricting physical activity has a negative influence on cognition. It is, however, suggested that loneliness, another aspect of an impoverished environment, has an even higher negative impact on cognition (Chida et al., 1995). Already in an early period in life, isolation causes memory problems (Kogan et al., 2000), attention deficits (Heidbreder et al., 2000), disruption of inhibitory control in attentional selection (Schrijver and Wurbel, 2001), reduction in information processing (Bartasaghi et al., 2006) and deficits in learning (Frisone et al., 2002; Huang et al., 2002), e.g., rule learning (Jones et al., 1991) or reversal learning (Jones et al., 1991; Schrijver et al., 2004). Reversal learning requires the inhibition of previously learned responses which has been associated with prefrontal-corticostratial functioning (Cacioppo and Hawkley, 2009). Also, in adult male mice, isolation for 60 days causes a decrease and delay in their learning performances (Manni et al., 2009), possibly due to changes in dopamine metabolism in the PFC (Jones et al., 1992). Old isolated rats had more learning problems compared to social rats after 70 days (Bell et al., 2009).

It is suggested that brain damaged animals are more sensitive to the effects of their environment than normal animals (Bouchon and Will, 1983). This implies that brain damaged animals suffer a greater disadvantage from impoverished environments than normal animals. If this also applies to

humans, the environment is especially important for people with brain damage, e.g., dementia and stroke.

Human experimental studies

Community-dwelling

Many studies with healthy older people describe 'successful aging', but cognitive components of successful aging are in the minority compared to physical functioning (Depp et al., 2010). Factors, i.e., genetics, (neuro)biological, emotional/psychological, and social/environmental determinants, associated with a positive effect on cognitive functioning have already been reviewed (Depp et al., 2010). Research describing the opposite is, however, scarce; e.g. to what extent does impoverished environment contribute to unsuccessful cognitive aging.

Physical inactivity

From 39% to 95% of US adults from 65 years and older and 100% of European adults of at least 70 years of age do not meet the recommendations for physical activity levels (Davis and Fox, 2007; Haskell et al., 2007; Troiano et al., 2008) (Table 1). Overall, the daily minutes in, e.g., moderate activity is frequently obtained, but activity session durations are often too short to meet the criteria (Orsini et al., 2008). For example, a small sample of older Australian people (71 years old) spent a total of 429 min/day upright, including 298 min standing and 130 min walking (Egerton and Brauer, 2009). However, they had a median session of 8 min, and 75% of the sessions shorter than 17 min. None of them participated in more than two episodes per week of moderate intensity physical activity (Egerton and Brauer, 2009). Out of 15 participants, one was extremely sedentary and was not upright for even 15 min/day at all, which was not due to health problems (Egerton and Brauer, 2009). The level of activity of European people seems even worse; almost half of them did not perform any session of 10 min of moderate physical activity (Davis and Fox, 2007). Another study with younger American participants (57 years) showed a median of 32 min of moderate physical activity per day (Banda et al., 2010). However, the sessions of physical activity that lasted at least 10 min contained only 4.6 min of moderate intensity (Banda et al., 2010). Overall,

Table 1 Physical activity recommendations for adults.

- ≥ 30 min of moderate-intensity for 5 days/week in one continuous session or more sessions of at least 10 min (Haskell et al., 2007; Nelson et al., 2007).
Lower or higher intensity activities increase or decrease the duration and frequency, respectively.
A combination of different intensity activities is possible.
- $\geq 2 \times$ /week strengthening and flexibility exercises for older adults (Nelson et al., 2007).
Strengthening: 8–10 exercises, 10–15 repetitions per exercise.
Flexibility: at least 10 min.

older people spend more time on sedentary to low-intensity activities, e.g., lying, sitting, standing [<3 metabolic equivalents units, i.e., a value to rate energy expenditure of activities compared to rest (Ainsworth et al., 2000)], instead of moderate- and high-intensity activities than younger adults (Meijer et al., 2001; Davis and Fox, 2007; Matthews et al., 2008; Peters et al., 2010a). After age 70 years, people spend more than 66% (>9 h) of their waking hours in sedentary behavior (Matthews et al., 2008). This sedentary behavior increases in a linear trend with age (Matthews et al., 2008), as also seen in the mean number of daily steps people between age 70 and 75 years make (5661 steps/day) compared to people older than 80 years (3410 steps/day) (Davis et al., 2011). Both of these groups do not achieve the recommended 7500 steps a day which corresponds to approximately 30 min of moderate physical activity (Tudor-Locke, 2010).

The studies addressed above used objective measurements with accelerometers. The subjective amount of physical activity would probably be higher, because (older) people often indicate higher levels of physical activity than indicated by objective measurements (Troiano et al., 2008; Banda et al., 2010; Peters et al., 2010b). In addition, the prevalence of sedentary people assessed by questionnaires varies from 14% to 41% (Carlson et al., 2009), which emphasizes the limitations of self-reported physical activity habits (Clark et al., 2009; Harris et al., 2009).

Sedentary people not only have lower cognitive performances compared to people who perform physical activities, they also show a faster decline in cognitive performance (Laurin et al., 2001; Scarmeas et al., 2001, 2009; Yaffe et al., 2001, 2009; Weuve et al., 2004; Podewils et al., 2005; Middleton et al., 2010; Plassman et al., 2010; Rolland et al., 2010; Williams and Kemper, 2010). Most studies show that a sedentary midlife or youth is associated with a faster cognitive decline and higher risk of dementia (Friedland et al., 2001; Dik et al., 2003; Weuve et al., 2004; Rovio et al., 2005; Middleton et al., 2010), but not all studies show this association (Carlson et al., 2008). Perhaps in this study the intensity of the physical activity was too low; a lower intensity and frequency of physical activities lacks association with cognition (Verghese et al., 2009). A meta-analysis showed that sedentary people can enhance their cognitive functioning, especially executive functions, by exercise training (Colcombe and Kramer, 2003) which indicates that these people are not performing at their highest cognitive level with a sedentary lifestyle. The opposite direction has also been observed: people who decrease the intensity of their physical activities show a faster cognitive decline compared to those who have a stable intensity level (van Gelder et al., 2004; Angevaren et al., 2010).

Loneliness

Frail older people in the society spend more than 50% of their days alone (Pruchno and Rose, 2002). More loneliness, i.e., less social networks and social engagement, is related to low cognitive performances and a faster cognitive decline in older people with or without cognitive impairment (Fratiglioni et al., 2004; Bennett et al., 2006; Karp et al., 2006; Cacioppo and Hawkley, 2009; Krueger et al., 2009; Andrew and Rockwood,

2010; Conroy et al., 2010), especially concerning executive functioning (Cacioppo and Hawkley, 2009). Another review did not report such firm conclusions due to low quality of evidence; this review missed evidence due to high demands for inclusion (Plassman et al., 2010). Social activities during midlife are also related to a reduced dementia risk (Carlson et al., 2008). Community-dwelling older people with dementia report that their needs for social interaction and participation in activities are largely unmet (Meaney et al., 2005). Those with higher age, lower mini mental state examination (MMSE) scores, and living alone have greater levels of unmet needs (Meaney et al., 2005). These aspects result unfortunately in a higher risk of moving into a nursing home which is an even more impoverished environment, which will be addressed in the next section.

Institutionalized

Physical inactivity By 1966 it was already observed that continued hospitalization has a negative effect on cognition in elderly residents (Howard, 1966). Others also observed that cognitive functioning of old people in various institutional settings is worse than the cognitive functioning of the community-dwelling aged (Winocur and Moscovitch, 1983, 1990). Even when these groups are carefully matched on different variables such as age, intelligence and health, most residents show an impaired function in frontal and medial-temporal lobe brain regions compared to their counterparts in the community (Winocur and Moscovitch, 1990). These brain regions play an important role in executive functioning and memory (Elderkin-Thompson et al., 2008; Wang et al., 2010). Animal experimental studies (see above) suggest that this might be due to the impoverished nature of nursing homes.

A nursing home can reflect a passive environment; in one study, more than 30% of the residents reported a decrease in physical activity during their stay in a nursing home, despite their largely positive attitude towards physical exercise (Ruuskanen and Parkatti, 1994). As a result, ambulatory residents sit down for long periods (MacRae et al., 1996) and they spend daily only 137 min upright, including 94 min standing and 43 min walking (Egerton and Brauer, 2009). These walking activities were split into several sessions with a median duration of 4 min, and as a result these residents rarely spend 30 min continuously upright, and some (four out of 16) did not stay upright for more than 10 min/day (Egerton and Brauer, 2009). Other studies confirm that residents show primarily sedentary behavior (Voelkl et al., 1995; Chin A Paw et al., 2006; Flick et al., 2010). Most studies show that especially residents with dementia rarely do anything (Perrin, 1997; Kolanowski et al., 2006; Hill et al., 2010); when they are not in bed during the daytime they sleep 30% of the time (Schnelle et al., 1998). By contrast, one study observed more participation in activities in residents with mild to moderate dementia compared to those without dementia, possibly due to their required engagement in rehabilitation (Voelkl et al., 1995). These residents spend most of their activity time in therapeutic activities (Chung, 2004), but this amount becomes less when they have severe dementia (Voelkl et al., 1995; Buettner and Fitzsimmons, 2003; Chung, 2004; Kolanowski et al., 2006).

In nursing homes, an extreme form of physical inactivity is physical restraint. Physical restraints are often used to immobilize residents (Feng et al., 2009; Meyer et al., 2009) with the consequence that these people are sitting or lying down for 94% of the day (MacRae et al., 1996). Persons who are physically restrained are not able to explore their environment, have less personal interaction and are dependent on others for their daily routines, such as going to the toilet. Impoverished environment by use of physical restraint (with or without the combination of neuroleptic use) is associated with cognitive decline (Burton et al., 1992; Castle, 2006; Engberg et al., 2008), more than those who are not restrained (Castle, 2006; Castle and Engberg, 2009). It should be noted that not all nursing homes use physical restraints often (Gulpers et al., 2010; Zwijsen et al., 2011). It is striking that some unrestrained residents are even less active than residents who are immobilized by physical restraints (MacRae et al., 1996).

Many residents take psychoactive drugs that causes sedation (Kolanowski et al., 2006; Beier, 2007), but also environmental restrictions might explain the low levels of physical activity (Chen, 2010). The engagement in activities of residents is among others dependent on the availability and quality of the activity programs (Voelkl et al., 1995). Concerning the amount and type of activities, nursing homes do not respond to the (individual) needs of their residents, especially not to those with sleep disturbances who exhibit excessive sleepiness during the day (Flick et al., 2010; Garms-Homolova et al., 2010). In addition, nursing homes underestimate the abilities of these residents resulting in unchallenging activities (Flick et al., 2010). For example, in one study 20% of the residents received occasional activities such as singing or cooking and 12% received daily activities, but these activities were considered inappropriate based on the level of functioning or the individual's interest (Buettner and Fitzsimmons, 2003). There is a tendency that staff overemphasizes the deficits in residents with dementia and that they fail to recognize and stimulate the abilities residents still have (Malone and Camp, 2007). However, when independence is promoted, residents with moderate to severe dementia can achieve more than is typically observed during daily interactions (MacPherson et al., 2009).

Residents not only have low activity levels when they are out of bed, they also spend an excessive time in bed while not being ill (Schnelle et al., 1998; Alessi et al., 1999; Bates-Jensen et al., 2004). For example, between 07:00 h and 19:00 h 8–18% of the residents in 15 different Californian nursing homes spend almost 10 h in bed (Bates-Jensen et al., 2004). In total, most of the residents were more than 17 h/day in bed (Bates-Jensen et al., 2004). In another study, the time in bed differed from 1.7 to 4.6 h (mean is 3.2 h) between 08:00 h and 17:00 h according to direct observations (Schnelle et al., 1998).

Loneliness Institutions are often an impoverished environment, not only due to the very low levels of physical activity; the amount of social isolation is also higher compared to community-dwelling elderly (Kostka and Jachimowicz,

2010). When people move into a nursing home, they experience difficulty maintaining their social relationships with friends (Barkay and Tabak, 2002; Drageset, 2004) and new friendships with other residents remain scarce and superficial (Buckley and McCarthy, 2009). More than half of the residents with or without dementia experience loneliness (Scocco et al., 2006; Drageset et al., 2010). High frequencies of social contact with family and friends from outside the institution is important to reduce residents feelings of loneliness (Drageset, 2004; Buckley and McCarthy, 2009).

Other institutions

Not only nursing homes show impoverished environments, but also acute care stroke units. In one study, 58 patients were observed for two weeks during their stay in a stroke unit directly after the stroke (Bernhardt et al., 2004). Stroke severity ranged from mild to severe, but only nine patients were restricted to bed, due to among other things unstable blood pressure, reduced consciousness and infection. The non-restricted people spent 49% of the time in bed. Patients with more severe strokes spent more time in bed than patients with mild stroke. In addition, for more than 60% of the day the patients were alone, and 15–24% of the time family or friends were the only people present. Therapists spent only 5% of the time with the patient and most of this time was in or beside the bed. There were limited opportunities to move away from the bedside, which becomes clear in the high proportion of time patients spent in their rooms, i.e., almost 90%. These low levels of physical activity did not change within two weeks.

Barriers to improve physical activity and loneliness in nursing homes

There is a lot of variation in the quality of care nursing homes give. Some nursing homes try to improve this quality together with residents (Phillips et al., 2007). Low quality is often caused by poor pay, shortage of qualified workers and high rates of staff turnover (Morley, 2010). However, in the care of physical activity and loneliness most nursing homes fall short in the 21st century despite the stimulation of physical activity since 1974 (Ice, 2002). The barriers to use non-pharmacological interventions include: more impaired residents compared to the 20th century and the inability of the staff to interact and reach out to the residents with dementia (Kolanowski et al., 2010). Successful use of non-pharmacological interventions requires staff with an appropriate education (Kolanowski et al., 2010). In future, technological advances, such as robots who serve as companions and assistants, are suspected to increase quality of life in the elderly (Robinson and Reinhard, 2009).

Conclusions

- Animals, especially old animals, living in an impoverished environment perform worse and show a faster decline in cognitive functioning compared to animals in a standard

environment. This decline in cognitive functioning is, however, reversible after three months in a standard or enriched environment.

- Sedentary and lonely people have worse cognitive functions and show a faster cognitive decline than physically and socially active people.
- Most community-dwelling older people do not meet the recommended levels of physical activity.
- Cognitive performances are worsened when people move into institutions due to their impoverished environments; residents spend an excessive time in bed, show mainly sedentary behavior, and often have feelings of loneliness.
- Physical restraints are associated with cognitive decline.

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